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The Appalachian Highlands Science Learning Center (AHSLC) is part of a network of research learning centers in the national park system established to increase the amount and effectiveness of research and research-based education. Located in Great Smoky Mountains National Park, and serving the parks of the Appalachian Highlands Monitoring Network (Blue Ridge Parkway, Big South Fork National River and Recreation Area, Great Smoky Mountains National Park, and Obed Wild and Scenic River), staff at the AHSLC often collaborate with researchers to develop ways to extend their field season using citizen scientists. One of the longest running citizen science projects sponsored by the AHSLC is an ozone biomonitoring garden project.

This project is a direct offshoot of research originally funded through a grant from the National Geographic Society (project no. 6617-99) and later continued under funding from the National Park Service's Natural Resource Preservation Program (NRPP) (PMIS no. 66941). The research was headed up by a team of five researchers, but the two who specifically assisted National Park Service staff in developing the student monitoring program were Howard Neufeld, Appalachian State University, Boone, North Carolina, and Arthur Chappelka, Clemson University, Clemson, South Carolina.

One objective of the research study was to determine the relationship between ambient ozone concentrations and the growth and reproduction of native wildflowers both *in situ* and in bio-indicator gardens. The researchers set up ozone biomonitoring gardens composed of plants that were genetic clones of one another. Gardens were located at three different elevations in Great Smoky Mountains National Park, with the highest-elevation garden at the AHSLC (5,000 feet). Ideally, these plants should be monitored once every two weeks during the growing season, but researchers were only in the park for two weeks total, which meant they were missing important information about the plants they were studying. To assist the research team, staff at the AHSLC began training high school summer interns in how to collect field data during the team's absence. This allowed the staff to let the researchers know important information, such as when the plants first begin showing symptoms and how quickly the rate of symptoms progressed. The students did such a competent job collecting data that the education staff decided to modify the protocols a bit to use with 7th grade students and other high school students participating in day-use education programs in at the AHSLC. The education program that grew out of the research fulfills the needs of several audiences; it allows scientists to communicate the needs for and the result of their research to a non-traditional audience, and it gives classroom educators a way to teach a difficult subject in an engaging manner.

The education portion of ground-level ozone biomonitoring has been developed in a way to encourage teachers to use inquiry-based teaching methods as recommended by the National Science Education Standards. Inquiry-based learning, which is student-driven,

encourages students to seek solutions to their own scientific questions. This differs from hands-on science, which is teacher-directed and is designed to confirm scientific ideas that are already known by the teacher. The style of learning the teacher wants to focus on is flexible depending on a teacher's classroom goals. A teacher may decide to teach a lesson about air pollution and have students collect data in their own schoolyard garden to illustrate an effect of ozone on plants. This would be hands-on science. If the teacher wanted to move the student towards inquiry-based learning, he/she might pose a question for the students to answer with their data, such as "Are our data different from the data collected at Purchase Knob in Great Smoky Mountains National Park?" Students would then have to search the Hands on the Land database to answer a question that was provided to them. An even more inquiry-based technique a teacher can use would be to let students choose from a list of provided questions or allow them to pose their own question using methods directed by the study. Total inquiry-based teaching would entail the student posing their own unique question that integrates the garden data posted on the Hands on the Land website. The student, rather than the teacher, would determine what data are needed and what other sources of information are needed. Since data are posted in a raw form on the Hands on the Land website, a teacher is able to utilize a spectrum of teaching styles.

Methods

The wildflowers in the ozone biomonitoring gardens in Great Smoky Mountains National Park were randomly collected in the field. Species and locations included cutleaf coneflower *(Rudbeckia laciniata* L. var. *laciniata)* and crownbeard *(Verbesina occidentalis* L.). Gardens were then established at three different locations in the park so that comparisons of the rate of ozone symptoms could be made.

A six-point scale is used to rate the relative severity of symptoms (1 = 0%, 2 = 1–6%, 3 = 7–25%, 4 = 26–50%, 5 = 51–75%, 6 = 76-100%). The lowest eight leaves of each plant are rated for foliar injury symptoms, which include ozone stippling, chlorosis, and necrosis. Various measures of plant growth are also collected, such as height, total number of leaves, flower presence, and any other observations.

Before students collect data, they are required to practice their foliar injury estimation skills on an internet training site (http://mona.psu.edu/scripts/FhWeb2.dll/intro). Details on how to use this site are available in the Ozone Bio-monitoring Garden's training section on the Hands on the Land website (www.handsontheland.org/monitoring/projects/ozone/ozone_bio_search.cfm).

Each student who is going to collect data must score 80% or better on 10 leaves and can't be more than one rating category off in their guess. A 20-minute video about air pollution in the Southern Appalachian Mountains is also available for teachers to show to students, giving them required background knowledge. This video is produced by the North Carolina Mountain Air Quality Coalition and is geared towards an upper-elementary age group.

Student groups collect data at least bi-weekly from June until the first hard frost. Ozone levels are tracked daily at Purchase Knob using data from a real-time internet weather and air quality website (www2.nature.nps.gov/air/webcams/parks/grsmpkcam/grsmpkcam.cfm).

Other sites may use the GLOBE Program's Surface Ozone protocols to obtain their current ozone levels using one-hour exposure cards and a Zikua card reader (www.globe.gov).

Data for each plant are collected by students working in pairs, with one person collecting data and the other recording. Each plant is visited by three pairs of data collectors in order to ensure data quality. If there is a discrepancy in the data, then the garden supervisor will visit the plant in question to determine which data are accurate. All data are then posted to an internet database. Data from any participating garden can be viewed, graphed, compared, animated over time, or otherwise analyzed. This website also contains a detailed "Implementation Guide" (www.handsontheland.org/monitoring/projects/ozone/ozone_bio_search.cfm).

This original park-centered project has grown into a citizen science education program where each year approximately 300 middle school, high school, and college students and teachers learn about the visible effects of an invisible pollutant. Additionally, over 75 companion gardens have been set up in locations as far west as Dallas, Texas, and as far north as Maine. The protocol for this project is also being added to the GLOBE network as an "Advanced Atmosphere Study." Evaluations show that this student-centered, citizen science monitoring project has succeeded in making the invisible (ground-level ozone) visible to students. Teachers applaud the real-world and relevant nature of the study, and scientists appreciate the extension of their field season.